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Optimization Of Surface Roughness Of Stainless Steel AISI 440 C Using Response Surface Methodology (RSM).

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Abstract

Because of its high corrosion resistance and ability to preserve mechanical qualities at high temperatures, Stainless steels are used in a variety of applications, including automotive, aerospace, and marine. In metal turning, cutting speed, feed rate, and depth of cut are all essential machining parameters . The settings of these parameters determine the quality of the final turning results. The goal of this research is to see how changing these parameters affects the output factor (Surface Roughness). In addition, the behavior of stainless steel 440 C in dry turning conditions is being investigated for purpose to improve cutting conditions. In response surface methodology (RSM), the box-behnken design (BBD) technique is used, the surface roughness was modeled as a result to the parameters of cutting. The 17 trial runs were built using Design Expert (v12) to develop and test the empirical surface roughness mathematical model. The results indicated that the roughness is strongly affected by the feed rate, followed by cutting speed and depth of cut.

.***Keywords:***Optimization,Response Surface Methodology,Suface Roughness,CNC Turning.

1. Introduction

One of the most essential performance metrics is surface roughness. Because of its association with many other mechanical features such as tool life, adjustment capacity, and wear resistance, it is also considered one of the most useful technological factors. To find the significant elements determining roughness, many authors employed analysis of variance (ANOVA).**[1].** H. E. Radhi, M.J. Alsalhy they conducted a surface roughness optimization study for turning AISI 1025 carbon steel on a CNC machine with a carbide cutting tool, and they found that the feeding rate had the largest influence on surface roughness. **[2]**. S. Thamizhmanii, S. using CBN and PCBN cutting tools, the machinability of hard martensitic stainless steel AISI 440 C and SCM 440 alloy steel was examined. Surface roughness, flank wear, force of cutting and specific cutting pressure were all measured. According to the data, at high cutting speed and low feeding rate, CBN tools provide lower surface roughness values than PCBN tools. **[3]**. Chauhan, S. R.,Dass, Kali researchers evaluated the performance of titanium alloy for turning using response surface methodology (RSM). Cutting parameters such speed of cutting , feeding rate, cut depth, and cutting edge approach angle were all taken into account in this study. Surface roughness and tangential powers are the research response variables. Face-centered, central composite design (CCD) employing response surface methodology (RSM) was the experimental approach for four components over three phases. According to the results of the research, roughness of surface increases by rising speed of cutting and feeding rate and decreases by decreasing speed of cutting and feeding rate. **[4]**. Deshpande, Rahul RPant, Reena they analyzed EN8 alloy steel specimens to discover which input parameters have the most influence on response variables. The Taguchi method was used to determine key parameters (ANOVA Statistical Techniques were employed to analyze the data) they are find out the spindle speed, followed by feed and depth of cut, is the most important factor in determining the roughness of the surface (Ra) and the rate of material removal (MRR)**[5]**. Mahdavinejad, R. A., Saeedy, the behavior of austenitic stainless steels AISI 304 was investigated, and turning settings were optimized to produce the best results. Turning tests were carried out with three different feed rates and cutting speeds, as well as with and without fluid of cutting. Cutting speed is the most important factor in flank wear, while feed rate is the most important factor in surface roughness, according to analysis of variance (ANOVA) **[6]**.M. Y. Noordin et al. investigated the use of response surface methodology in describing how coated carbide tools perform when turning AISI 1045 steel. Cutting speed, feed, and the angle of the side cutting edge were all studied. Surface finish and tangential force were the response factors. They were discovered that the most significant factor influencing the response variables tested, according to ANOVA, is the feed **[7]**. A. Doniavi et al utilized response surface methodology (RSM) to construct an empirical model for predicting surface roughness in turning by calculating the best cutting conditions. The researchers discovered that the feed rate had a significant impact on surface roughness. Surface roughness was shown to rise with an increase in feed rate and decrease with an increase in cutting speed. The analysis of variance revealed that feed and speed had a greater influence on surface roughness than depth of cut **[8]**. M. Xiao et al. they used the response surface method (RSM) and the Taguchi design approach of central combination design to test the turning of stainless steel 1Cr18Ni9Ti. Cutting parameters (cutting speed, feed rate, and cutting depth) were studied to see how they affected surface roughness. The second-order RSM was used to create the surface roughness prediction model. The findings reveal that feed rate has a considerable impact on surface roughness. Cutting depth comes in second, and cutting speed has the least impact **[9]**. V. Jakhar, et al they compiled and investigated different literature on optimizing process parameters for turning and summarized the most critical cutting parameters and the most commonly utilized surface finish optimization procedures. It has been observed that several strategies for reducing surface roughness are applied by adjusting cutting settings such as cutting speed, feed rate, depth of cut, tool angle, nose radius, cutting fluid, etc. In optimization of surface roughness found to be, the feed rate is the most significant factor, followed by the depth of cut and cutting speed **[10]**. N. Shankar and S. P. Ramachandran experimentally studied the ceramic cutting tool and using it in the machining process on a CNC machine for machining martensitic stainless steel 416, the major cutting parameters of cutting velocity, feed, and depth of cut are chosen. Following the optimization of machining characteristics, the renowned Taguchi method is applied with the help of Mini Tab software. To establish the veracity of the previously obtained experimental results, confirmation tests were carried out for the optimal machining parameters. They discovered that cutting speed (1000 RPM), feed (0.2 mm/rev), and cutting depth (0.05 mm)are the optimum input parameters for minimizing surface roughness **[11].**Many researchers have conducted substantial research on the optimization process of machining using various methodologies, which can be found at **[14]**,**[15]**,**[16]**. Various variables were investigated in the current study, with the goal of determining the impact of machining conditions on surface roughness utilizing response surface methods for dry turning AISI 440 C stainless steel.

Studies identified in the literature above indicate the importance of analyzing the turning process and knowing the process parameters. Several studies on turning reveal that variables such as cutting velocity, feed rate, and depth of cut have a significant impact on response (surface roughness).

In the current study the impact of cutting conditions (cutting speed, feeding rate, and depth of cut.) on surface roughness was experimentally investigated. The experiments were conducted in dry conditions for the purpose to obtined the optimal outcomes in dry turning.

2. Experimental procedures

2.1 Equipments and materials

The machining experimental tests in this work are carried out on a CNC machine (Star Chip 450) in dry conditions. The workpiece material employed in this study is astainless steel AISI 440 C grade with the following dimensions: 100 mm in length and 38 mm in diameter. Tables (1) and (2) show the chemical composition and mechanical characteristics, respectively **[12]**. The device (PCE-RT 1200) was used to measure the surface roughness in this study, as shown in Fig. (1a).Which has a sensor that reads the rough areas of the material using a tiny stylus that glides horizontally on the workpiece for a predefined distance, after the device had been calibrated using a stander calibrated plate Fig. (1b). Then by amplifying the obtained electrical signal from the stylus and displaying it on the output screen the results can be obtained. According to ISO 4287: 1997 standard specification **[3]**, the arithmetic average height (Ra) metric was discovered to measure the surface texture. As a result, measurements of surface roughness were made under various cutting parameters, as shown in table (4).

Table 1 Chemical composition of AISI 440 C **[12]**

Elements	% of weight
Carbon	0.95 to 1.20 %
Phosphorus	0.040 %
Silicon	1.00 %
Molybdenum	0.75 %
Manganese	1.00 %
Sulfur	0.030 %
Chromium	16.00 to 18.00 %
Iron	77.98 to 80.23 %

Table 2 Mechanical Properties of AISI 440 C **[12]**

Grade	440 C	
Density (kg/m3)	7650	
Elastic Modulus (GPa)	200	
Mean Coefficient of Thermal Expansion (mm/m/°C)	(0-100) C°	10.1
	(0-200) C°	10.3
	(0-600) C°	11.7
Thermal Conductivity(W/m.K)	At 100 C°	24.2
	At 500 C°	-
Specific Heat(J/kg.K)	(0-100) C°	460
Electrical Resistivity (nW.m)	600	
Hardness (HRC)	45-55	
Tensile strength (MPa)	758	
Elongation %	14	

(a) (b)

Fig.1(a) Surface roughness measurement device (PCE-RT 1200). (b) Surface roughness calibration plate

2.2 Experiment design

Cutting experiments are setting and carried out using a Box-Behnken Design (BBD) by three-level with three cutting parameters: cutting speed, feed rate, and depth of cut. A total of 17 tests are carried out. For a three-level full factorial experimental design, Table (3) displays the low–middle–high level of cutting parameters.

2.3 Box-Behnken design (BBD)

BBD is the most labor-efficient response surface design available in RSM, and it's suitable for fitting second-order polynomial equations with three or more experimental factors.
George E. P. Box and Donald Behnken developed Box-Behnken designs in 1960 for response surface methodology in statistics to fulfill the following goals Fig.1(a) Surface roughness measurement device (PCE-RT 1200). (b) Surface roughness calibration plate **[17]**:

- Each independent variable, or component, is given one of three equally spaced values, often denoted by the letters -1, 0, or 1. (The following aim requires at least three levels).

The design should be capable of fitting a quadratic model, which includes squared terms, two-factor products, linear terms, and an intercept.In the quadratic model, the number of experimental points to the number of coefficients should be reasonable.

Table 3 Cutting parameters and their levels

Parameters	**level 1**	**level 2**	**level 3**
Spindle speed (RPM)	500	1000	1500
Feed (mm/rev)	0.05	0.125	0.2
Depth of cut (mm)	0.5	1	1.5

The estimation variance should be proportional to the distance from the center and should not change significantly within the smallest cube comprising the experimental points.
Figure.5 shows the three-variable Box–Behnken design. As can be seen, the Box-Behnken design is a spherical design with all points on a sphere of radius $\sqrt{2}$. In addition, there are no points at the vertices of the cubic zone generated by the upper and lower bounds for each variable in the Box – Behnken design **[18]**.

2.4 Response surface methodology (RSM)

RSM is a set of statistical and mathematical methodologies which was developed for the first time by Box and Wilson in 1951 and it has been widely utilized **[13]**. The optimal experimental design and input parameter selections have a significant impact on the response surface methodology (RSM) technique's success.

A fundamental feature of response surface methodology (RSM) is the capacity to assess and determine the relationship between input parameters and the impact they have on outputs (responses). In this study, BBD method regression analysis is used to describe the relationship between the output parameter (surface roughness) and the input parameters (cutting speed, feed rate, and depth of cut), which is areliable approach of assessing if variables have an impact on a given problem. Can clearly determine

which parts are most significant, which factors may be overlooked, and how these factors interact using regression analysis.

Table 4 Surface roughness results in different conditions

Exp. No.	Speed(rpm)	Feed mm/rev	D.O.C. mm	Run -1	Run -2	Run -3	Ra (μm)
1	500	0.05	1	1.322	1.405	1.428	1.385
2	1500	0.05	1	1.350	1.295	1.405	1.35
3	500	0.2	1	1.982	1.786	1.932	1.9
4	1500	0.2	1	1.673	1.441	1632	1.582
5	500	0.125	0.5	1.498	1340	1.662	1.5
6	1500	0.125	0.5	1.526	1.485	1.510	1.507
7	500	0.125	1.5	1.369	1.522	1.405	1.432
8	1500	0.125	1.5	1.961	1.887	2.002	1.95
9	1000	0.05	0.5	1.811	1.825	1.836	1.824
10	1000	0.2	0.5	1.236	1.416	1.389	1.347
11	1000	0.05	1.5	1.346	1.438	1.266	1.35
12	1000	0.2	1.5	2.178	2.034	2.109	2.107
13	1000	0.125	1	1.217	0.976	1.215	1.136
14	1000	0.125	1	1.067	1.188	1.312	1.189
15	1000	0.125	1	1.447	1.312	1.174	1.311
16	1000	0.125	1	1.302	1.185	1.164	1.217
17	1000	0.125	1	1.147	1.006	1.201	1.118

3 Results and discussion

Table (4) shows the experimental values of several surface roughness (Ra) criteria. These results were achieved using 17 full factorial designs with varied combinations of cutting parameters (cutting speed, feed, and depth of cut).

The outcomes of the quadratic model used in this Experiment are summarized in Tables 5 and 6. This shows how important each component, such as speed, feeding, and depth of cut, is in determining surface roughness.The F-value, P-value, and R^2 coefficients are all included in these tables. Rather than just one variable, the overall significance of an ANOVA model is measured using F-values. The higher the F-value,the more accurate the model.A p-value of less than 0.05 suggests that the model represents a significant relationship.
The R^2 value indicates how well the model explains the data; a higher R^2 value implies a better model.
The model F-value of 6.66 in Table 5 suggests that the model is significant. Because of noise, an F-value of this size has a 1.03% probability of occuring. Model terms with a P-value of 0.05 or less are significant, If the p-value is more than 0.1, the model terms are unimportant.

The acceptability of the model may be checked by looking at the R^2 value of 89.54 percent in table 6. This model can be used to navigate the design space.
In Fig. 2, the distribution of actual and predicted surface roughness values is displayed. The majority of the spots are clearly on either side of the 45°slope line.

Figures 3&4 demonstrate thesurface roughness with the lowest value 1,167 μm was apparent at 853.442 rpm of cutting speed, 0.08 mm/rev of feed rate (f), and cutting depth of 1 mm. As the feed rate (f) increases, the surface roughness (Ra) will increase. With increasing cutting speed, the surface roughness (Ra) increases as well.Surface roughness (Ra) is highly influenced by the feed rate (f). It was observed that the depth of cut has a slight effect on the surface roughness
When comparing the findings of this study to the findings of other researchers, it is obvious that the results in terms of surface roughness are similar.
Hessainia et al. for metal cutting, a surface roughness model was developed utilizing the response surface methodology (RSM), such as turning hardened steel with Al_2O_3/TiC mixed ceramic cutting tools, the feed rate (f) was found to be the most critical influence in surface roughness **[19]**.
O. L. A. Cle RSM was employed in metal cutting applications such as hard turning bearing steel with mixed

ceramic inserts, and it was discovered that the feed is the most important factor which effect on surface roughness, followed by nose radius and cutting speed **[20]**.

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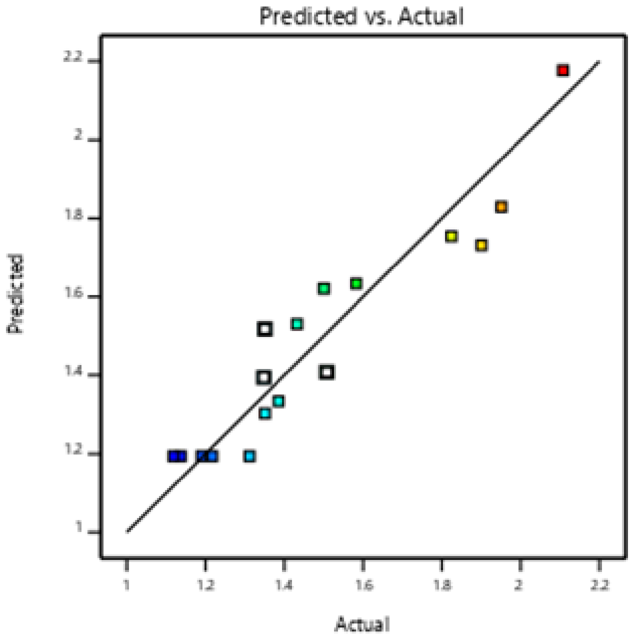

Fig.2 Actual vs. predicted value of surface roughness (Ra)

Test	Factors		
	A	B	C
1	-1	-1	0
2	1	-1	0
3	-1	1	0
4	1	1	0
5	0	0	0
6	0	-1	-1
7	0	-1	1
8	0	1	-1
9	0	1	1
10	0	0	0
11	-1	0	-1
12	-1	0	1
13	1	0	-1
14	1	0	1
15	0	0	0

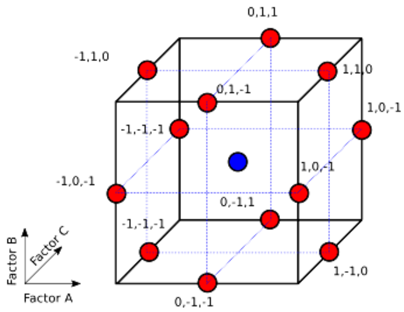

Fig.5 Box-Behnken design (three factors)

Table 5 Roughness of surface analysis of variance**(ANOVA)**

Source	Sum of squa-res	df	Mean squa-res	F-value	P-value	
Model	١,٢٧	9	٠,١٤٠٨	٦,٦٦	٠,٠١٠٣	Significant
A	٠,٠٠٣٧	1	٠,٠٠٣٧	٠,١٧٤٩	٠,٦٨٨٣	
B	٠,١٣١٨	1	٠,١٣١٨	٦,٢٤	٠,٠٤١٢	
C	٠,٠٥٤٦	1	٠,٠٥٤٦	٢,٥٨	٠,١٥٢٠	
AB	٠,٠٢٠٠	1	٠,٠٢٠٠	٠,٩٤٧٠	٠,٣٦٢٩	
AC	٠,٠٦٥٣	1	٠,٠٦٥٣	٣,٠٩	٠,١٢٢٣	
BC	٠,٣٨٠٧	1	٠,٣٨٠٧	١٨,٠١	٠,٠٠٣٨	
A^2	٠,٠٩٤٩	1	٠,٠٩٤٩	٤,٤٩	٠,٠٧١٨	
B^2	٠,١٨٥٥	1	٠,١٨٥٥	٨,٧٧	٠,٠٢١٠	
C^2	٠,٢٦٩٣	1	٠,٢٦٩٣	١٢,٧٤	٠,٠٠٩١	
Residual	٠,١٤٨٠	7	٠,٠٢١١			
Lake of Fit	٠,١٢٤٦	3	٠,٠٤١٥	7.11	0.0443	Significant
Pure Error	٠,٠٢٣٤	4	٠,٠٠٥٨			
Cor. Total	١,٤١	16				

Table 6 Roughness of surface: an analysis of variance

Std.Dev.	٠,١٤٥٤
Mean	١,٤٨
C.V.%	٩,٨١
R^2	٠,٨٩٥٤
AdjustedR^2	٠,٧٦٠٩
Predicted R^2	-٠,٤٣٥١
Adeq. Precision	٨,٨٠٨٤

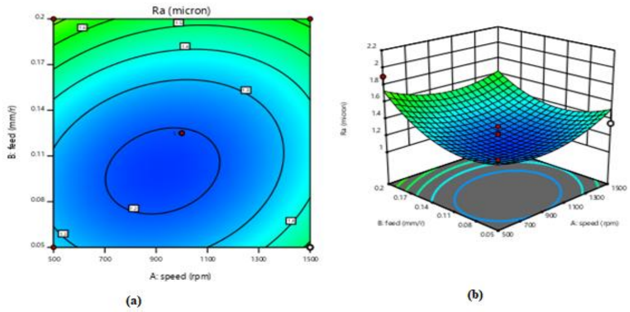

Fig.3 (a) contour plot of interaction speed and feed for surface roughness. (b) 3D plot for surface roughness of interaction speed and feed.

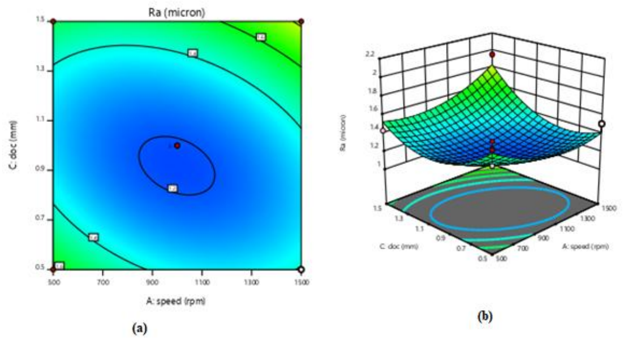

Fig. 4 (a) contour plot of interaction speed and depth of cut for surface roughness. (b) 3D plot for surface roughness of interaction speed and depth of cut.

.3.1 Modeling of (Ra)

The Box-Behnken method was used to conduct transformation experiments. Using the Design Expert (version12) statistical program, an analysis was carried to identify the relationship between input parameters and response (surface roughness). Linear and quadratic regression were performed, and the quadratic regression was shown to be best based on R^2 values. Equation below shows a mathematical model for predicting the roughness of the surface.

Regression equation for surface roughness (Ra)

$$Ra = 1.19+0.0215\ A+0.1284\ B+0.0826\ C-0.0708\ AB+0.1278\ AC+0.3085\ BC+0.1501\ A^2+0.2099\ B^2+0.2529\ C^2$$

Where: **Ra**=Surface Roughness (μ m), A= Cutting Speed (rpm), B=Feeding rate (mm/rev.), C=Depth of cut (mm).

4 Conclusion

In order to construct statistical models of surface roughness criteria, turning tests of AISI 440 C stainless steel were investigated. These models were created in Design Expert program using regression and response surface techniques. A regression analysis was performed to determine the relationship between input factors (cutting speed, feed rate, and depth of cut) and response (surface roughness) using Design Expert program.Surface roughness is observed to be reduced at lower feed rates values of 0.05 mm/rev and higher at higher feed rate values of 0.2 mm/rev.

The following conclusions can be obtained from the results and analysis:

1. Feeding rate a significant impact on the various roughness criteria investigated.
2. The predicted and experimental value was extremely close to each other, indicating that the mathematical model established might be used effectively in turning..
3. The ideal cutting parameters of stainless steel AISI 440 C have been discovered using response surface optimization and RSM's method: The speed is 853.442 rpm, the feed is 0.08 mm/rev, and the depth of cut is 1 mm.

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